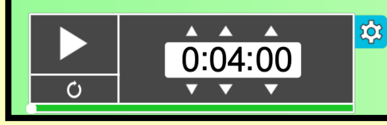
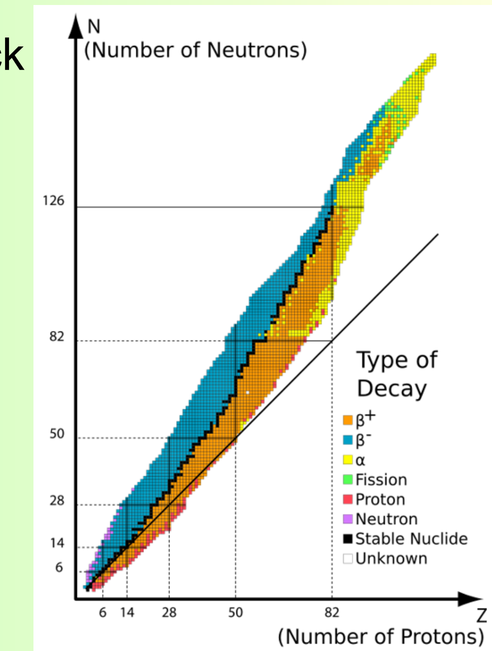
Particle physics	**The nucleus**

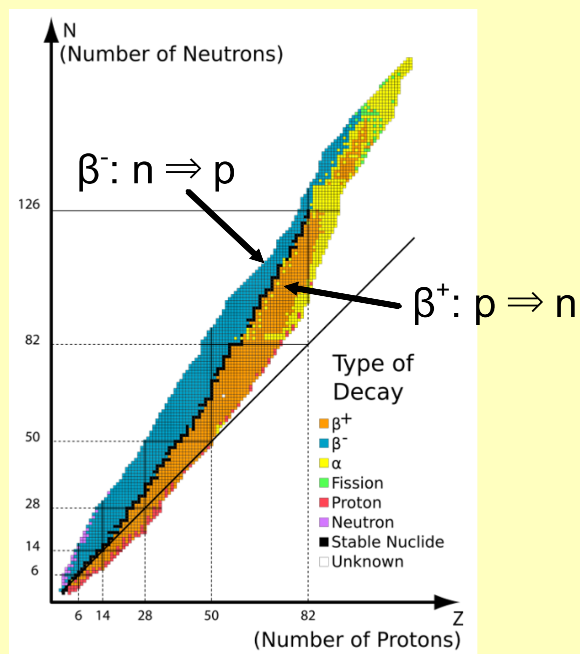
Learning objectives	**MUST (C)**	Describe nuclei in nuclear notation
	SHOULD (B)	Describe the characteristics of the strong nuclear force
	COULD (A/ A*)	Apply the equation to calculate the radius of nuclei and estimate the density of nuclear matter

STARTER: Look carefully at the diagram. The black line shows stable nuclides. What conclusions can you draw?

EXTENSION: How do the different types of decay affect the nucleus?







Particle physics	**The nucleus**
MUST (C)	Describe nuclei in nuclear notation

Isotopes are atoms of the **same** number of **protons,** but **different** number of **neutrons.**

A specific combination of protons and neutrons is called a **nuclide.**

$^{238}_{92}\mathrm{U}$ What do these numbers mean?

$^{A}_{Z}\mathrm{X}$

Mass number - number of protons + number of neutrons. **(nucleons)**

Atomic number - number of protons

Chemical symbol

Neutrons: A - Z

Electrons (for a non-ionised atom): Z

What can you tell me about this nuclide? Can you suggest anything about its likely stability/decay?

$^{100}_{50}\mathrm{Sn}$

0:02:00

Tin-100 (discovered 1994). Tin is the element with the highest number of stable isotopes (ten, with another 29 unstable isotopes). This nuclide has 50 protons and 50 neutrons: this 1:1 ratio is not enough for stability (as the chart shown earlier suggests) and it has a half-life of 1.1 seconds and decays by β+ emission in which a proton is converted to a neutron.

Atomic mass units

Masses of particles can be expressed in **atomic mass units (u)**, where 1 u is 1/12th the mass of a neutral carbon-12 atom.

Particle	electron	proton	neutron	helium-4 nucleus	carbon-12 nucleus
Mass / u	0.00055	1.00728	1.00867	4.00151	11.99671

Particle physics	**The nucleus**

SHOULD (B)	Describe the characteristics of the strong nuclear force

Earlier in the year we looked at the electrostatic repulsion and gravitational attraction between two protons: what did we find, and what does this imply about the nucleus?

Extension: I didn't specify how far apart the protons are. Why not?

0:01:00

$$F_E = k\frac{ee}{r^2} \ \& \ F_g = G\frac{m_p m_p}{r^2}$$

$$\frac{F_E}{F_g} = \frac{ke^2}{Gm_p^{\ 2}} = 1.29x10^{36}$$

The electrostatic repulsion is far greater than the gravitational attraction: in protons, the ratio is about 1.2 x 10^{36}

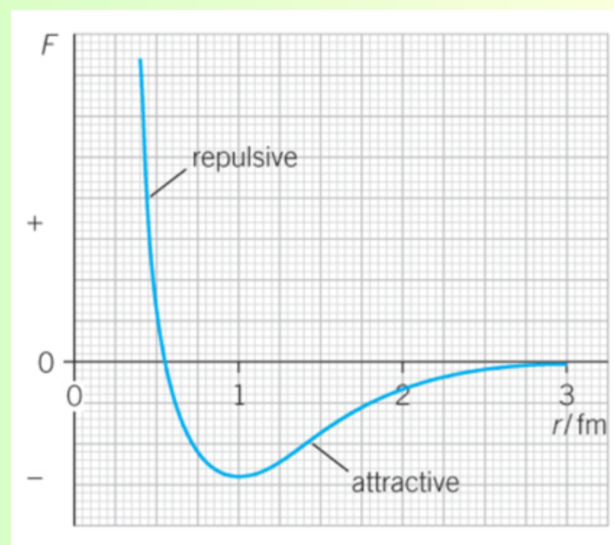
Therefore, there must be another force holding the nucleons together in a nucleus.

The strong nuclear force

The strong nuclear force acts between **all nucleons**, and only acts over an extremely short range.

From your diagram, explain and describe the ranges over which the strong nuclear force is a) repulsive and b) attractive.

The table on your diagram sheet shows how the strong nuclear force compares to the other forces.



Particle physics	**The nucleus**
COULD (A/ A*)	Apply the equation to calculate the radius of nuclei and estimate the density of nuclear matter

The radius, R, of a nucleus is related to the number of nucleons, A, by:

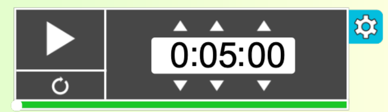
$$R = r_0 A^{\frac{1}{3}}$$

$r_0 \approx 1.2$ fm

Estimate the density of a nucleus. Use one of the nuclei from your table, calculate its radius from the equation given.

Table 1 *The masses of some particles in atomic mass units (u), where 1 u = 1.661×10^{-27} kg.*

Particle	electron	proton	neutron	helium-4 nucleus	carbon-12 nucleus	iron-56 nucleus	uranium-235 nucleus
Mass / u	0.00055	1.00728	1.00867	4.00151	11.99671	55.79066	234.99343



Worked example: Density of a helium nucleus

Calculate the approximate density of a helium-4 nucleus and of a helium atom.

Step 1: Calculate the volume of the helium-4 nucleus.

volume of nucleus $= \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(r_0 A^{\frac{1}{3}})^3 = \frac{4}{3}\pi r_0{}^3 A$

volume of nucleus $= \frac{4}{3}\pi \times (1.2 \times 10^{-15})^3 \times 4 = 2.895... \times 10^{-44}\,\text{m}^3$

Step 2: The approximate mass of the helium-4 nucleus is 4 u, and density $= \frac{\text{mass}}{\text{volume}}$.

density of nucleus $= \frac{4 \times 1.661 \times 10^{-27}}{2.895... \times 10^{-44}} = 2.3 \times 10^{17}\,\text{kg m}^{-3}$ (2 s.f.)

Step 3: The mass of the electrons is negligible, so the mass of the helium atom is about 4 u. It has a radius of about 10^{-10} m.

density of atom $= \frac{4 \times 1.661 \times 10^{-27}}{\frac{4}{3}\pi \times (10^{-10})^3} = 1600\,\text{kg m}^{-3}$ (2 s.f.)

Extension: A neutron star has approximately the same density as a nucleus. If a neutron star had a mass of 2.8×10^{30} kg (about 1.4 solar masses) what would its radius approximate?

2.8×10^{30} kg/2.3×10^{17} kg/m^3 = 1.2174×10^{13} m^3

1.2174×10^{13} m^3 = (4/3)πr3

$r^3 \approx 1.2174 \times 10^{13}$ m^3 /((4/3)*π)

$r^3 \approx 2.906 \times 10^{12}$

$r \approx 1.43 \times 10^4$, or about 14 km

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PLENARY: Neutron stars have approximately the same density as a nucleus. How do they form? What are the implications for their physical properties?

Neutron stars explained